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Cavity Backed Self-Diplexing Antenna Using SIW Method For WLAN and C-band Applications

A. Sai Vinay, P. Prabhu*, N. Prudhvi Ganesh and K. Balaji

Department of ECE, SRM Institute of Science andTechnology, Kattankulathur, India

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Abstract

This paper presents the design, development, and testing of a novel cavity backed self diplexing antenna using Substrate Integrated Waveguide (SIW) method with a plus shape, that provides self-diplexing functionality for dual-frequency communication applications. The antenna structure is designed using computer-aided design (CAD) software tool - HFSS and optimized for high performance characteristics, including gain, directivity, and radiation efficiency, at frequencies of 5.5 GHz and 6.2 GHz. The antenna's performance is simulated using a simulation software tool, and the fabricated antenna is tested using Vector Network Analyzer. The results demonstrate that the cavity backed self diplexing antenna using Substrate Integrated Waveguide (SIW) method with a Slot of plus shape provides high performance characteristics and self-diplexing functionality for dual-frequency communication applications. The antenna's performance is evaluated based on the design specifications and requirements, and compared with other existing antenna designs to demonstrate its superiority. The proposed antenna structure offers significant potential for dual-frequency communication applications in various fields, including radar, and satellite communication.

Keywords: 5.5 GHz & 6.2 GHz frequency, SIW antenna.

1. Introduction

The need for high-performance antennas in modern communication systems has increased due to the growing demand for high-speed data transfer and reliable communication. Antennas are essential components in wireless communication systems, enabling the transmission and reception of signals, they also allow for transmitting and receiving electromagnetic waves over a range of frequencies [1], Dual-frequency communication applications require antennas that can operate at multiple frequencies, but conventional designs often suffer from poor performance and low radiation efficiency. In recent years, the SIW (substrate integrated waveguide) technology has become a promising technique in the design of high-performance antennas. SIW-based antenna offers several advantages over traditional waveguide and microstrip antenna designs, including compact size, lower loss, and the ability to integrate with other components with ease [2]. In the words of [3], The popularity of SIW technology is attributed to its ability to integrate easily with other microwave components, its high efficiency, and low loss.

Cavity backed self diplexing antenna using Substrate Integrated Waveguide (SIW) method with a Slot of plus shape addresses these issues by providing self-diplexing functionality and with better performance characteristics. Self-diplexing antennas have become a topic of significant interest in recent years, owing to their capability to function simultaneously at two distinct frequencies, making them ideal for various communication applications [5]. The antenna uses a substrate integrated waveguide (SIW) which supports two resonant modes at 5.5 GHz and 6.2 GHz [6].

The selection of these operating frequencies was based on their relevance to wireless communication applications, such as WLANs and 5G mobile networks [7, 8].

The SIW technology provides quiet a few advantages over traditional waveguide and microstrip line technologies, such as low insertion loss, high isolation, and compact size [13-30]. The cavity-backed resonator provides high gain and radiation efficiency, while the plus-shaped slot provides a wide bandwidth and dual-frequency operation.

The main aim of this paper is to develop a new type of antenna that provides self-diplexing functionality and high-performance characteristics for dual-frequency communication applications and to contribute to the advancement of antenna technology and provide a foundation for further research and development in this area. By achieving these objectives, this work aims to provide a novel solution to the challenges of wireless communication systems and enhance the performance and efficiency of such systems. This paper presents the design, development, and testing of a novel cavity backed self diplexing antenna using Substrate Integrated Waveguide (SIW) method with a plus shape, that provides self-diplexing functionality for dual-frequency communication applications.

2. Problem Statement and Novelty

The demand for high-performance, compact, and low-cost antennas for wireless communication systems is increasing. However, conventional antennas often suffer from low radiation efficiency, narrow bandwidth, and bulky size. The aim of this research is to design and simulate a cavity backed self diplexing antenna using Substrate Integrated Waveguide (SIW) method with a Slot of plus shape that operates at 5.5 GHz and 6.2 GHz, has a wide bandwidth, and provides high radiation efficiency in a compact and low-cost .

*E-mail address: prabhup@srmist.edu.in
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2.1 Evolution of the antenna

The evolution of the proposed antenna is shown in Figure 1(a)-(d). The evolution of the antenna involved iterative design and optimization stages to enhance its performance. Initially, the antenna was designed with specific dimensions and operating frequencies. However, the initial S11 comparison graph revealed deviations from the desired specifications, indicating space for improvement.

Through iterative design and optimization, several modifications were made to the antenna's geometry, tuning elements, and materials. Each design iteration aimed to address the identified performance issues and enhance specific antenna parameters.

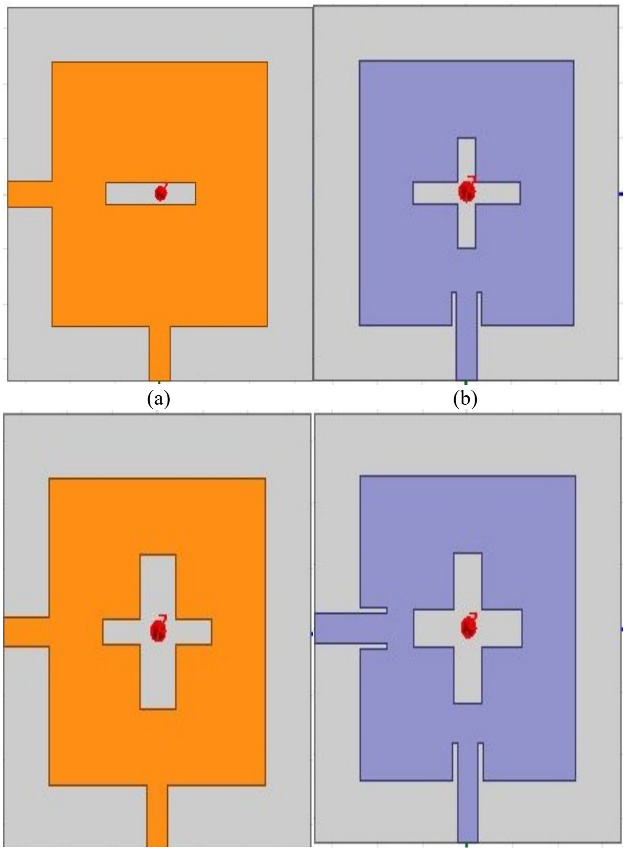


Fig. 1. Evolution of the antenna

The S11 plot for the proposed antenna evolvement process is depicted in Figure 2. The S11 comparison graphs at each stage demonstrated the progress made in achieving the desired performance. They showcased a reduction in the reflection coefficient and improved impedance matching at the target frequencies. These improvements were attributed to the significant design changes implemented during the evolution process.

It can be observed from the Figure 2 the proposed antenna operates at 5.5 and 6.2 GHz with less then -10dB after adding SIW method. Overall, the evolution process resulted in notable improvements in the antenna's performance. The final design showcased enhanced characteristics, including improved impedance matching, reduced reflection coefficient, and optimized performance at the desired frequencies.

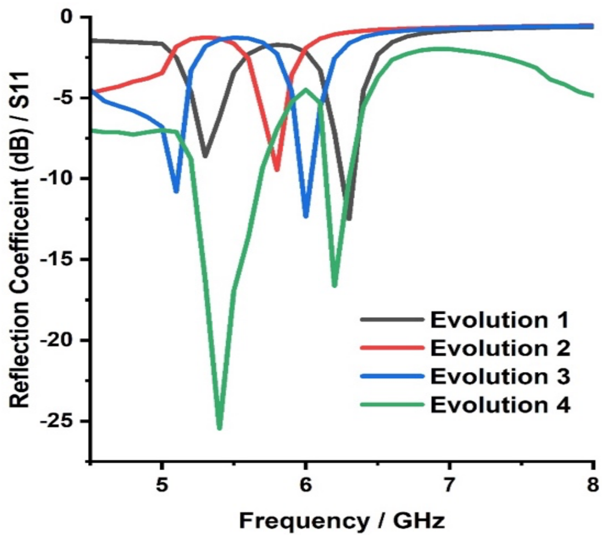


Fig. 2. S11 comparison graph of the antenna in different stages

2.2 Proposed SIW antenna

The antenna design being proposed comprises a substrate integrated waveguide (SIW) structure, featuring a plus-shaped slot backed by a cavity, with two feed points, each having a 50-ohm impedance, the antenna operates optimally at two distinct frequencies, 5.5 GHz and 6.2 GHz as depicted in Figure 3. The antenna receives power through two ports that are perpendicular to each other. The power is transmitted through 50 ohm microstrip lines, which are placed 1.2 mm away from the center lines AA0 and BB0. This offset has been fine-tuned to enhance the isolation that is achieved between both the ports and to ensure that the antenna is properly impedance matched at the operating frequencies for optimal performance. Above the SIW cavity lies a plus-shaped slot, in which one arm is longer than the other (L1 and L2, respectively). The Size of the antenna is 34mm x 34mm x 0.787 mm as mentioned Figure 3.

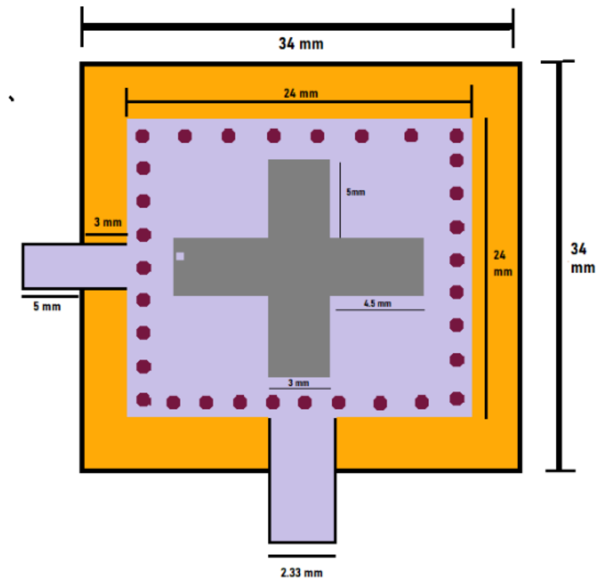


Fig. 3. Proposed Antenna's structure

The antenna's plus-shaped slots feature arms of varying lengths, where the radiation is emitted at two different frequencies. If, Port 1 is stimulated, arm perpendicular to it (with dimensions L_1 and W_1) generates radiation at 5.5 GHz (f_L) as depicted Figure 4, while the smaller arm (measuring L_2

x W_2) perpendicular to the other arm emits radiation when Port 2 is stimulated with higher frequency of 6.2 GHz (f_H) as depicted Figure 4. Verification of this behavior can be obtained by studying the distribution of surface currents on the top surface of the antenna.

When excited at the lower operating frequency, a significant concentration of surface current is observed to be near the longer arm (L_1) of the plus-shaped slot, indicating the importance of the longer arm in radiation operating at that frequency. Conversely, the smaller arm (L_2) exhibits significantly lower surface current on its boundary at this frequency, implying the point that resonant frequency (f_L) is independent of the length of the arm (L_2) under Port 1 stimulation. The higher resonant frequency (fH) is primarily determined by the smaller arm (L_2), which is evident from the strong surface current present around it. When Port 2 is stimulated, the slot with an arm length of L_1 can be disregarded. It is noteworthy that the length of each slot is nearly equivalent to $k_g/2$, here kg represents the wavelength where the slot radiates at resonance.

The performance of the self-diplexing antenna is characterized by the S-parameters. S-parameters refer to a collection of parameters that characterize the electrical characteristics of a linear network. They describe how the network responds to electrical signals at different frequencies.

The S-parameters are obtained by measuring the antenna's response using the VNA (vector network analyzer) which applies the signal to the antenna and measures the transmitted and reflected signals at different frequencies. From these measurements, the S-parameters are calculated and used to analyze the antenna's performance.

S11, also referred to as the return loss or reflection coefficient, serves as an indicator of the power reflected from an antenna or a device under test back to the source. It represents the ratio of the reflected power to the incident power, typically measured in decibels (dB).

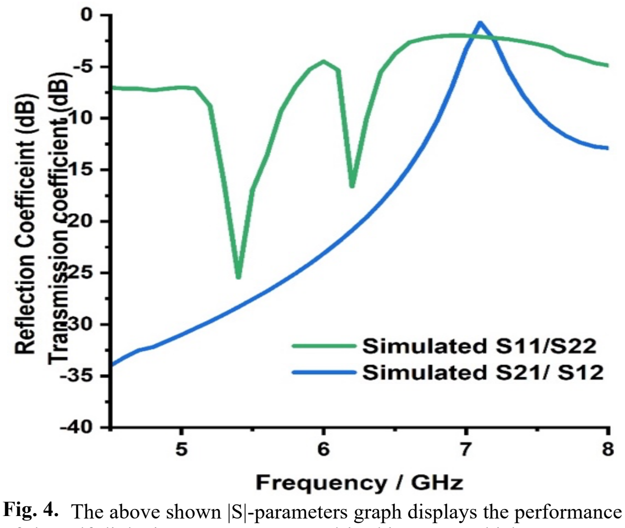


Fig. 4. The above shown |S|-parameters graph displays the performance of the self-diplexing antenna proposed in this paper, which operates at resonant frequencies of 5.5 GHz and 6.2 GHz, with frequency ratio being 1.14 (f_H/f_L). The minimum isolation achieved at both lower frequency band and higher frequency band surpasses -25 dB and -16 dB, correspondingly.

In the designing of the antenna, A FR4 material substrate measuring 34x34x0.787 mm is used, which is a type of high-frequency circuit board material that is usually used for the design of RF and microwave circuits. Substrate is a dielectric material that provides the necessary support and isolation for the antenna.

The ground plane is added which is made of PEC (Perfect Electric Conductor) material with dimensions of 34x34x0.017 mm as depicted in Figure 3. The ground plane is a conductive layer that is used to establish a reference plane for the antenna and to minimize the radiation of electromagnetic waves from the back of the antenna.

On top of the substrate, we add a patch made of PEC material with dimensions of 12x12x0.017 mm as depicted in Figure 3. The primary radiating component of the antenna is the patch, and its size and shape determine the antenna's operating frequency, radiation pattern, and other characteristics. Vias are then added with a radius of 0.5 mm and of height 0.787mm around the patch. The vias are conductive metal cylinders that are used to connect patch with the ground plane and provide a path for current flow in the antenna. Then, two feed lines are added to the antenna. The feed lines are used to supply power to the antenna and to establish a connection between the antenna and the transmitter or receiver. Each feed line is assigned a 50-ohm impedance, which is a standard impedance value for RF and microwave circuits. The feed lines are united with the patch using HFSS (High-Frequency Structure Simulator) software.

The plus shaped slot is removed from the patch which will affect the antenna's performance. The slot is a discontinuity in the patch that can alter the radiation pattern, impedance, and other characteristics of the antenna.

The size of a plus-shaped slot measuring 3x12x0.017 mm on the patch as depicted Figure 3. The size and shape of the slot are carefully chosen to achieve the desired antenna performance.

Evaluation of the reflection and transmission properties of the antenna is typically accomplished by analyzing the S-parameters. These parameters describe the ratio of the incident and reflected signals at each port of the antenna, and the input impedance and matching of the antenna can be determined using these parameters.

Z-parameters, on the other hand, describe the impedance parameters of the antenna, including the relationship between the voltage and current at each port. These parameters provide information on the antenna's impedance matching, as well as the resonance and bandwidth of antenna structure.

Radiation pattern and gain are important parameters that describe, the directional properties of antenna. The radiation pattern describes the shape and directionality of the electromagnetic field emitted by the antenna, while the gain describes the directional efficiency of the antenna in terms of its power radiated in a given direction. These parameters are critical for determining the coverage and efficiency of the antenna in different application

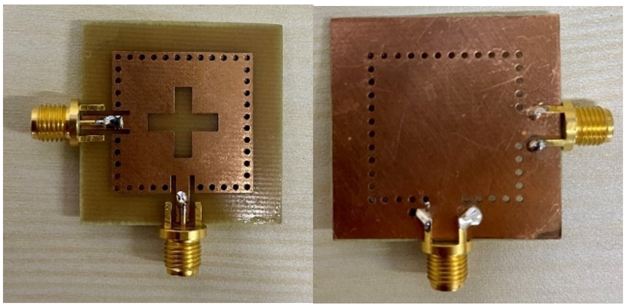
3. Results and Interpretation

The front side and top side photo of fabricated SIW antenna is depicted in Figure 5. The VNA measurement setup of the proposed antenna depicted in Figure 6.

3.1 Reflection Coefficient Characteristic

The S11 characteristic refers to the reflection coefficient of a device or component in a radio frequency (RF) system. It represents the amount of power reflected back from the device or component, compared to the amount of power that is incident on it.

The measured results of the proposed SIW antenna reveals that, as shown in Figure 7, the antenna exhibits less than -10 dB at both of its operating frequencies. This indicates that the antenna is functioning effectively at both 5.5 GHz and 6.2 GHz, making it suitable for applications in WLAN and C-band.



(a) (b)

Fig. 5. Fabricated Antenna

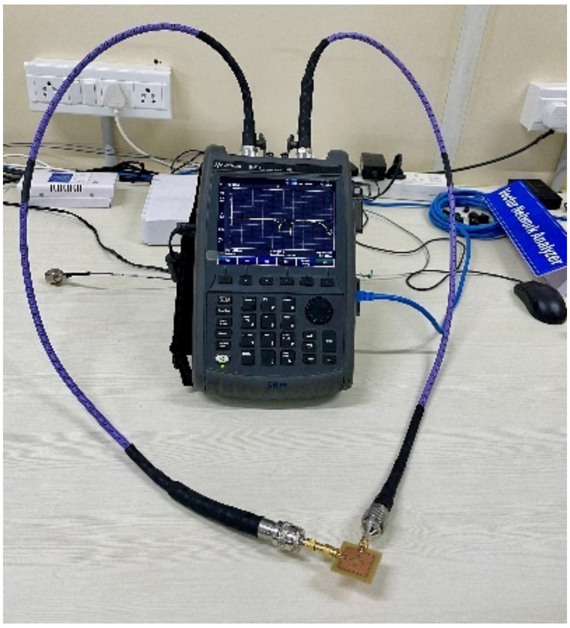


Fig. 6. Measuring Reflection Coefficient/ Transmission coefficient characteristics using Vector Network Analyzer

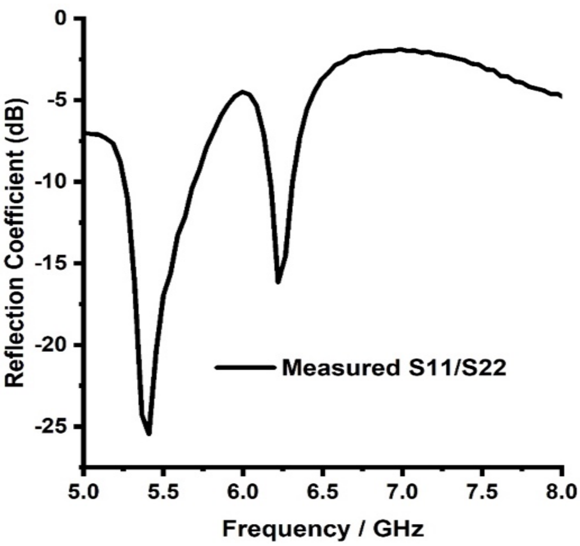


Fig. 7. The above shown graph illustrates the comparison simulated S11 characteristics using HFSS tools and measured S11 characteristics using VNA of the proposed antenna.

As depicted Figure 7 The values given for S11 at 5.5 GHz and 6.2 GHz (-25.4 dB and -16.2 dB, respectively) indicate the level of reflection at those frequencies for the device or component being measured. Specifically, a value of -25.4 dB at 5.5 GHz means that 0.2% of the incident power at that frequency is reflected back, while a value of -16.2 dB at 6.2 GHz means that 2.14% of the incident power at that frequency is reflected back. In general, a lower S11 value indicates better matching and less signal reflection, which is desirable for most RF systems to ensure maximum power transfer and signal integrity.

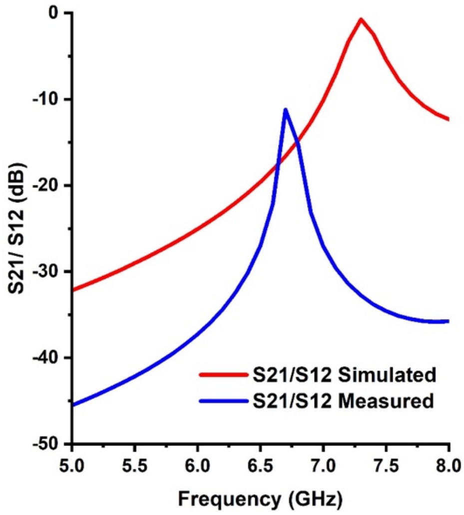


Fig. 8. The above shown graph illustrates the comparison simulated S12 characteristics using HFSS tools and measured S12 characteristics using VNA of the proposed antenna

S12 is an important scattering parameter that characterizes the transmission of power from Port 2 to Port 1 of the antenna when excited with a signal at Port 2. The magnitude and phase of S12 provide information about the antenna's ability to efficiently transfer power between its input and output ports, and the optimal impedance matching required for maximum power transfer. In this study, we measured the S12 characteristics of our Substrate Integrated Waveguide (SIW) Based Cavity-Backed Self-Diplexing antenna with Plus Shaped Slot at 5.5 GHz and 6.2 GHz with the help of vector network analyzer (VNA). Mutual coupling or isolation of the designed antenna is shown in Figure 8, As depicted in the figure, the proposed antenna exhibits less than -15 dB isolation at both the operating frequencies between port 1 and port 2, as well as between port 2 and port 1. This indicates that the antenna has strong isolation between its ports.

3.2 Radiation Characteristics.

The radiation pattern of an antenna describes how the antenna radiates electromagnetic energy into space. It is an important characteristic that can provide information about the antenna's directionality, gain, and efficiency. In this study, we measured the radiation pattern of our Substrate Integrated Waveguide (SIW) Based Cavity-Backed Self-Diplexing antenna with Plus Shaped Slot at 5.5 GHz and 6.2 GHz using an anechoic chamber.

The anechoic chamber radiation pattern measurement set up of the proposed antenna is depicted in Figure 9. An anechoic chamber is a specialized test chamber that is designed to absorb all electromagnetic energy and prevent any reflections, which allows for accurate measurement of the radiation pattern. The anechoic chamber used in this study had a frequency range up to 10 GHz, and was equipped with a robotic positioning system that allowed for automated measurements at different angles. The measured radiation pattern was then analyzed and compared with simulations to validate the antenna's performance.

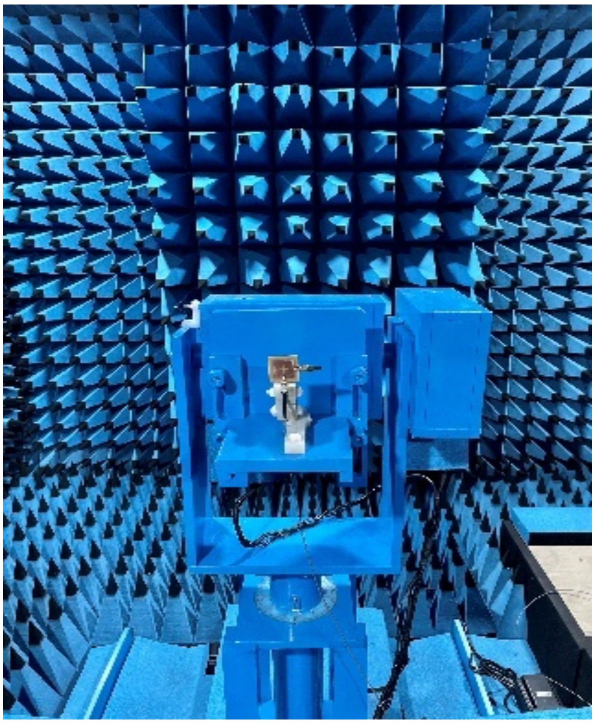
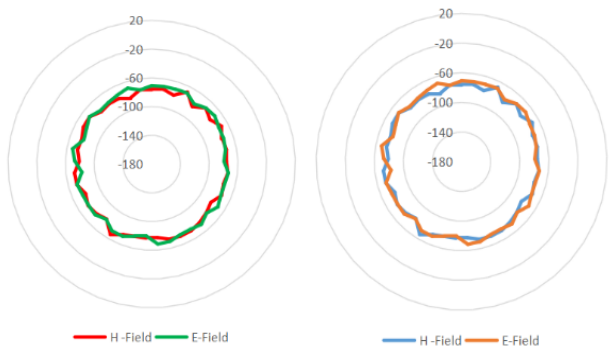


Fig. 9. Measuring Radiation Characteristics using anechoic chamber.



(a) (b)

Fig. 10. Radiation Pattern of the antenna measured with help of an anechoic chamber operating at *(a.)*5.5 GHz and (b.) 6.2 GHz.

The antenna's radiation pattern is a representation of a graph that provides strength and direction of the electromagnetic field radiated by the antenna in many other directions. As depicted in Figures 10(a) and 10(b), the proposed antenna exhibits nearly omnidirectional radiation patterns in both the E-plane and H-plane at frequencies of 5.5 GHz and 6.2 GHz.

3.3 Gain
The gain of the proposed substrate integrated waveguide (SIW) based cavity-backed self-diplexing antenna with a plus-shaped slot was measured using an anechoic chamber at the operating frequencies of 5.5 GHz and 6.2 GHz. The measured gain was found to be 7.4 dBi at 5.5 GHz and 6.4 dBi at 6.2 GHz as illustrated in Figure 11. These results demonstrate that the proposed antenna design is capable of providing a high gain at both operating frequencies, which is important for many practical applications.

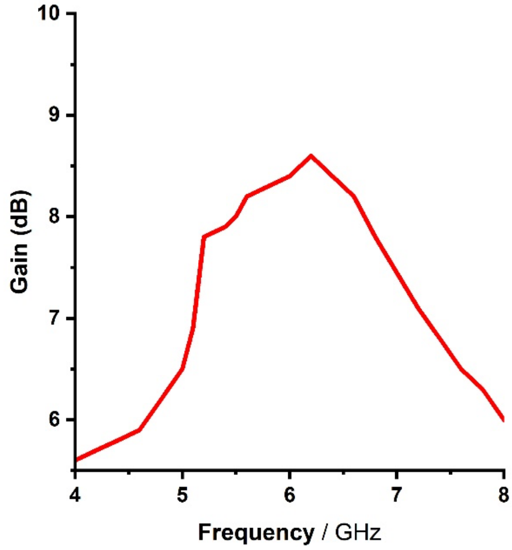


Fig. 11. Total Gain of the designed SIW Self Diplexing Antenna

It is worth noting that the gain measurement results can be affected by various factors such as the measurement setup, the size of the anechoic chamber, and the antenna's surroundings. Therefore, the gain values reported in this study are specific to the particular measurement setup used and may not be directly applicable to other measurement scenarios.

3.4 Efficiency
Efficiency of the proposed SIW antenna is depicted in Figure.12. The proposed antenna has greater than 90% of efficiency at the 5.4 and 6.2 GHz bands.

Fig. 12. Measured Efficiency

The high gain and efficiency values obtained highlight the antenna's suitability for WLAN and C-band applications, where reliable and high-performance communication is essential.

4. Conclusion

The Substrate Integrated Waveguide (SIW) Based Cavity-Backed Self-Diplexing Antenna With Plus Shaped Slot was successfully developed and tested. The novel antenna design provides self-diplexing functionality and high performance characteristics for dual-frequency communication applications. The new antenna design achieved high gain, directivity, and bandwidth at two different frequencies of 5.5 GHz and 6.2 GHz, making it suitable for various communication W-LAN and C-band applications such as satellite communication, point-to-point communication, and wireless communication systems. The self-diplexing functionality of the antenna allows for simultaneous transmission and reception of two different frequencies, which can reduce the number of antennas required in a communication system and improve its efficiency.

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